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चालू बिजली की लाईन पर कार्य करना—कारीगरों की ताप से रक्षा के कपड़ों हेतु ज्वाला प्रतिरोधी सामग्रियाँ—इलैक्ट्रिक आर्क के ताप जोखिम

भाग 1 परीक्षण पद्धति

Indian Standard

LIVE WORKING — FLAME-RESISTANT MATERIALS FOR CLOTHING FOR THERMAL PROTECTION OF WORKERS — THERMAL HAZARDS OF AN ELECTRIC ARC

PART 1 TEST METHODS

ICS 13.220:40:29.260.99

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NEW DELHI 110002

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Tools and Equipment for Live Working Sectional Committee, ET 36

NATIONAL FOREWORD

This Indian Standard (Part 1) which is identical with IEC 61482-1 (2002) 'Live working — Flame-resistant materials for clothing for thermal protection of workers — Thermal hazards of an electric arc — Part 1 : Test methods' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendations of the Tools and Equipment for Live Working Sectional Committee (ET 36) and approval of the Electrotechnical Division Council.

The text of the IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. In the adopted standard, certain terminology and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following.

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

Only the English text of the International Standard has been retained while adopting it as an Indian Standard, and as such the page numbers given here are not the same as in IEC Publication.

CROSS REFERENCES

The Technical Committee responsible for the preparation of the standard has reviewed the provisions of the following International Standards referred to in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

International Standard	*Title*
ISO 3175-2 : 1998	Textiles — Dry cleaning and finishing — Part 2 : Procedures for tetrachloroethene
ISO 6330 : 2000	Textiles — Domestic washing and drying procedures for textile testing
ISO 15025 : 2000	Protective clothing — Protection against heat and flame — Method of test for limited flame spread

For the purpose of deciding whether a particular requirement of this standard is complied, with final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

LIVE WORKING — FLAME-RESISTANT MATERIALS FOR CLOTHING FOR THERMAL PROTECTION OF WORKERS — THERMAL HAZARDS OF AN ELECTRIC ARC

PART 1 TEST METHODS

1 Scope

This part of IEC 61482 specifies test methods to measure the arc thermal performance value of materials intended for use in heat- and flame-resistant clothing for workers exposed to electric arcs.

These test methods measure the arc thermal performance value of materials which meet the following requirements: less than 100 mm char length and less than 2 s afterflame after removal from flame, when tested in accordance with ISO 15025, procedure B (bottom-edge ignition) on the outer material, and the char length measured using a modified ISO method as described in annex A.

These methods are used to measure and describe the properties of materials, products, assemblies or garments in response to convective and radiant energy generated by an electric arc in open air under controlled laboratory conditions.

The materials used in these methods are in the form of flat specimens for method A and shirts for method B. Method A is used to measure fabric response to arc exposure when tested in a flat configuration. Method B is used to measure clothing response to an arc exposure including all the garment findings, sewing thread, fastenings, fabrics and other accessories when tested on a mannequin torso.

It is the responsibility of the user of this part of IEC 61482 to establish appropriate safety and health practices prior to use. For specific precautions, see clause 7.

NOTE An alternative test method is under development to measure the same properties using a constrained and directed arc. This method will be added to this part of IEC 61482 when the equivalence to method A has been demonstrated.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3175-2:1998, *Textiles – Dry cleaning and finishing – Part 2: Procedures for tetrachloroethene*

ISO 6330:2000, *Textiles – Domestic washing and drying procedures for textile testing*

ISO 15025:2000, *Protective clothing – Protection against heat and flame – Method of test for limited flame spread*

3 Terms and definitions

For the purpose of this part of IEC 61482, the following definitions apply.

3.1
arc duration
time duration of the arc, in s

3.2
arc energy, $vidt$
sum of the instantaneous arc voltage values multiplied by the instantaneous arc current values multiplied by the incremental time values during the arc, in J or kW·s

3.3
arc gap
distance between the arc electrodes, in mm

3.4
arc thermal performance value (ATPV)
in arc testing, incident energy on a fabric or material that results in sufficient heat transfer through the fabric or material to cause the onset of a second-degree burn based on the Stoll curve, in kW·s/m^2

3.5
arc voltage
voltage across the arc, V

3.6
asymmetrical arc current
total arc current produced during closure; it includes a direct component and a symmetrical component, A

3.7
breakopen
in electric arc testing, material response evidenced by the formation of one or more holes in the material which may allow flame to pass through the material

NOTE The specimen is considered to exhibit breakopen when any hole is at least 300 mm^2 in area or at least 25 mm in any dimension. A single thread across the opening or hole does not reduce the size of the hole for the purposes of this part of IEC 61482.

3.8
breakopen threshold energy, E_{BT}
highest incident energy exposure value on a fabric or material below the Stoll curve where the specimens do not exhibit breakopen, in kW·s/m^2

3.9
charring
formation of carbonaceous residue as the result of pyrolysis or incomplete combustion

3.10
closure
point on supply current waveform where the arc is initiated

3.11
delta peak temperature
difference between the maximum temperature and the initial temperature of the sensor during the test, in °C

3.12
dripping
in testing flame-resistant clothing, material response evidenced by flowing of the fibre polymer

3.13
embrittlement
formation of a brittle residue as the result of pyrolysis or incomplete combustion

3.14
heat attenuation factor (HAF)
in electric arc testing, per cent of the incident energy which is blocked by a material at an incident energy level equal to ATPV

3.15
heat flux
thermal intensity indicated by the amount of energy transmitted per unit area and time, in kW/m^2

3.16
ignitability (ignitable)
in electric arc exposure, property of a material involving ignition accompanied by heat and light, and continued burning resulting in consumption of at least 25 % of the exposed area of the test specimen

3.17
ignition
initiation of combustion

3.18
monitoring sensors
sensors mounted on each side of the panel or mannequin, using the calorimeters described in 6.6, not covered by fabric and used to measure incident energy

3.19
incident energy, E_i
in electric arc testing, heat energy received at a unit surface area as a direct result of an electric arc, in kW·s/m^2

NOTE In an arc test, incident energy for a specimen is determined from the average temperature-rise response of the two monitor sensors adjacent to the test specimen.

3.20
material response
material response to an electric arc indicated by the following terms: breakopen, melting, dripping, charring, embrittlement, shrinkage, and ignition

3.21
melting
when testing flame-resistant clothing, material response evidenced by softening of the fibre polymer

3.22
peak arc current
maximum value of the a.c. arc current, in A

3.23
r.m.s. arc current
root mean square of the a.c. arc current, in A

3.24
sensor
device made of a non-conductive heat-resistant material in which the calorimeter is mounted

3.25
shrinkage
when testing flame-resistant clothing, material response evidenced by reduction in specimen size

3.26
Stoll curve
curve produced from data on human tissue tolerance to heat and used to predict the onset of second-degree burn injury (see table 1)

3.27
time to delta peak temperature
time from beginning of the initiation of the arc to the time the delta peak temperature is reached, in s

3.28
***X/R* ratio**
ratio of system inductive reactance to resistance. It is proportional to the L/R ratio of time constant, and is, therefore, indicative of the rate of decay of any d.c. offset. A large *X/R* ratio corresponds to a large time constant and a slow rate of decay

NOTE For definitions of other textile terms used in this part of IEC 61482, refer to ASTM D-123 [5][1].

4 Principle of the test methods

Both methods determine the incident energy which would predict a second-degree burn injury when the material(s) is(are) exposed to heat energy from an electric arc.

During the tests, the amount of heat energy transferred by the material(s) is measured during and after exposure to an electric arc.

The heat flux of the exposure and that transferred by the test specimen(s) are both measured with copper calorimeters. The rate at which the temperature of the calorimeters increases is a direct measure of the heat energy received.

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[1] Figures in square brachets refer to the bibliography.

Material performance for this procedure is determined from the amount of heat transferred by the specimen(s).

Heat transfer data is used to predict the onset of a second-degree burn using the Stoll curve.

The procedures incorporate incident-energy monitoring sensors.

Material response shall be further described by recording the observed effects of the electric arc exposure on the specimens using the terms in 3.20.

5 Significance and use of the test methods

The test methods measure the arc thermal performance value of materials intended for use in flame-resistant clothing for workers exposed to electric arcs. They are intended for the determination of the thermal performance value of a material by itself or in comparison with other materials.

Because of the variability of the arc exposure, different heat transmission values may result for individual sensors. Evaluate the results of each sensor in accordance with clause 12.

The test methods maintain the specimen in a static vertical position and do not involve movement except that resulting from the exposure.

The test methods specify a standard set of exposure conditions. Different exposure conditions may produce different results. In addition to the standard set of exposure conditions, other conditions representative of the expected hazard may be used.

6 Test apparatus

The test apparatus shall consist of the following elements:

- supply bus;
- arc controller;
- recorder;
- arc electrodes;
- three two-sensor panels or one to three four-sensor mannequins;
- monitor sensors for each panel or mannequin.

6.1 Method A – Arrangement of the two-sensor panels

Three two-sensor panels shall be used for each test and spaced at 120° as shown in figure 1. In addition, each two-sensor panel shall have two monitoring sensors. One monitoring sensor shall be positioned on each side of the two-sensor panel as shown in figure 2.

6.2 Panel construction

Each two-sensor panel and monitor sensor holder shall be constructed from non-conductive, heat-resistant material. Each two-sensor panel shall be 200 mm by a minimum of 550 mm as shown in figure 2. Each two-sensor panel and the monitoring sensors shall be adjustable from 200 mm to 600 mm from the centre line of the arc electrodes as shown in figures 1 and 3. Two sensors shall be mounted in the panel as shown in figure 2. Each sensor shall be mounted flush with the surface of the mounting board.

6.3 Method B – Arrangement of the mannequins

Up to three four-sensor mannequins shall be used for each test and spaced at a minimum of 120° as shown in figure 4. Each mannequin shall have two monitoring sensors. One monitoring sensor shall be positioned on each side of the mannequin as shown in figure 5.

NOTE The space around the arc electrodes may dictate the number of mannequins used. It has been found that two mannequins provide the best working space when dressing the mannequins. The minimum 120° spacing should be maintained.

6.4 Method B – Mannequin construction

A male mannequin torso, size large (chest width: 1 067 mm ± 25 mm), made from non-conductive fibreglass construction shall be used.

The mannequin shall be constructed in an erect posture; the head may be removable; the arms shall be detachable, straight and mounted in a vertical position to allow the test specimen at the chest to be the closest point to the centre line of the arc. The arms may be shortened to 100 mm to permit ease of specimen mounting. The mannequin shall use the sensors described in 6.2 and mounted as shown in figure 6.

6.5 Sensor response

Sensor response shall be compared with the Stoll curve. Monitor sensor response is converted to incident energy in units of kW·s/m^2 by multiplying the temperature increase (ΔT) by the constant factor 5,65 kW·s/m^2 K.

6.6 Calorimeter construction

The calorimeter shall be constructed from electrical grade copper with four thermocouple wires installed in the arrangement as shown in figure 7a. The thermocouple wire shall be installed in the calorimeter as shown in figure 7b. Figure 8 gives a typical installation of the calorimeter in the sensor and monitor sensor. For test exposures above 2 512 kW·s/m^2 only, alternate calorimeters for the monitor sensors may be used, provided they are calibrated and have an appropriate response.

6.7 Supply bus and electrodes

The arrangement of the supply bus and arc electrodes is shown in figure 9. The arc shall be in a vertical position as shown.

6.7.1 Electrodes

The electrodes are made from a stainless steel rod (alloy type 303 or type 304) of a suitable diameter and length which are practical for the test energies being utilized.

6.7.2 Fuse wire

A fuse wire, connecting the ends of opposing electrodes tips, is used to initiate the arc. This wire is consumed during the test; therefore, its mass shall be very small to reduce the chance of molten metal burns. The fuse wire shall be a copper wire with a nominal diameter of 0,05 mm.

6.8 Electric supply

The electric supply should be sufficient to allow for the discharge of an electric arc with a gap of up to 305 mm, with alternating arc current from 4 000 A up to 25 000 A and with arc duration from 0,05 s up to 1,5 s from a power-frequency supply. The source impedance shall be much higher than the arc impedance so that the r.m.s. current does not vary during the test.

6.9 Test-circuit control

The arc duration shall be within 0,2 cycle from test to test. The arc currents shall not deviate by more than 2 % from test to test. The make switch shall be capable of point on wave closing such that the closing angle will not deviate from test to test. The arc current, duration and voltage shall be measured. The arc current, duration, voltage and energy shall be displayed in graph form and stored in digital format.

6.10 Data acquisition system

The system shall be capable of recording voltage, current, and 12 calorimeter outputs. The temperature data shall be acquired at a minimum sampling rate of 50 ms/channel for 30 s. The current and voltage data should be acquired at a minimum rate of 2 kHz. The acquisition system shall be able to record temperatures to 250 °C with sufficient sensitivity to read sensor response to 1 °C for a single-layer system. For multiple-layer systems, the system shall be able to record temperatures to 400 °C. The system shall have a resolution of 0,1 °C and an accuracy of 1,5 °C.

NOTE Due to the nature of this type of testing, the use of isolating devices on the calorimeter outputs to protect the acquisition system is recommended.

7 Precautions

The test apparatus discharges large amounts of energy. In addition, the electric arc produces very intense light. Care shall be taken to protect personnel working in the area. Workers shall be behind protective barriers or at a safe distance to prevent electrocution and contact with molten metal. Workers wishing to view the test shall use very heavy tinted glasses. If the test is conducted indoors, there shall be a method to ventilate the area in order to carry away combustion products, smoke and fumes. This ventilation shall not be turned on before the test is completed. Air currents can disturb the arc reducing the heat flux at the surface of the sensor boards. The test apparatus shall be shielded by non-combustible materials suitable for the test area. The test apparatus shall be insulated from ground for the appropriate test voltage.

If outdoor tests are conducted, appropriate means shall be used to prevent the effect of weather conditions (wind, rain, etc.).

The electrodes and calorimeter assembly become hot during testing. Use protective gloves when handling these hot objects.

Use care when the specimen ignites or releases combustible gases. A fire extinguisher shall be readily available. Ensure that the materials are fully extinguished.

Immediately after each test, the electric supply shall be shut off from the test apparatus and all other laboratory equipment used to generate the arc, and the apparatus and other laboratory equipment shall be isolated and grounded. After data acquisition has been completed, appropriate methods shall be used to ventilate the test area before it is entered by personnel. No one should enter the test area prior to exhausting all smoke and fumes.

8 Sampling and specimen preparation

8.1 Test specimens for methods A and B

8.1.1 Test specimens for method A: two-sensor panel test

From the material to be tested, the size of the post-laundered specimen shall be at least 610 mm long and at least 305 mm wide. Refer to 11.2 to determine the number of samples.

The length direction of the specimen should be cut in the warp or weft direction of the material.

8.1.2 Test specimens for method B: four-sensor mannequin

Specially produced garments shall be made from the material to be tested, in accordance with standards for men's long-sleeve shirts, size large. No front pockets.

The fabric direction shall be that normally used for shirts.

8.2 Laundry conditioning of test specimens

Launder the required amount of material for the test specimens. Before testing, the test materials or clothing shall be washed five times in accordance with ISO 6330, method 2A, and drying by procedure E (tumble drying) unless otherwise specified in the care labelling. Materials or clothing which are labelled as dry cleanable only shall be dry cleaned five times in accordance with ISO 3175-2. Samples may be restored to a flat condition by pressing.

For those materials that require special cleaning other than the above, follow the manufacturer's recommended practice and note the procedure used in the test reports.

9 Calibration

9.1 Data acquisition system precalibration

The data acquisition system shall be calibrated by using a thermocouple calibrator/simulator. This will allow calibrations to be made at multiple points and at levels above 100 °C. The data acquisition system shall be calibrated. Due to the nature of the tests, frequent calibration checks are recommended.

9.2 Calorimeter calibration check

Calorimeters shall be checked to verify their operation.

After final placing within the test cell of all test panels/mannequins and monitor sensors, expose each calorimeter to a fixed radiant energy source for 30 s. Place a 500 W spotlight 267 mm from the calorimeter. The spot shall be centred on, and perpendicular to, the calorimeter. Measure and graph the temperature rise of each calorimeter and system response. At 30 s, no one calorimeter response shall vary by more than 4 °C from the average of all 12 calorimeters. Any calorimeter not meeting this requirement shall be suspected of faulty connections and shall be replaced.

9.3 Arc exposure calibration

Prior to each calibration, position the electrodes of the test apparatus to produce a 300 mm gap. The face of the monitor sensors shall be parallel and normal to the centre line of the electrodes. The mid-point of the electrode gap shall be at the same elevation as the centre point of the monitor sensors (see figure 3). Connect the fuse wire to the end of one electrode by making several wraps and twists and then to the end of the other electrode by the same method. The fuse wire shall be pulled tight and the excess trimmed. The test apparatus should be adjusted to produce the desired arc current and duration.

9.4 Apparatus calibration for the two-sensor panels, mannequins and monitor sensors

Position each two-sensor panel or mannequin so that the surface of each is 305 mm from, parallel and normal to, the centre line of the electrodes. Set the symmetrical arc exposure current to the test amperage level and the arc duration at 10 cycles.

Discharge the arc, determine the maximum temperature rise for each of the sensors, and multiply by the sensor constant 5,65 kW·s/m^2 K to obtain the incident energy (total heat) in kW·s/m^2 measured by each sensor.

Compare the highest sensor reading and the average value obtained for all sensors; for example, with the theoretical result of 423 kW·s/m^2 for the calibration exposure given in 11.1. Compare the total heat value determined by the sensors to the value shown. The average total heat calculated for the sensors shall be at least 60 % of the value determined by calculation or that shown. The highest measured total heat of any one sensor shall be within 10 % of the calculated value. If these values are not obtained, inspect the test set-up and correct the problems. An arc exposure calibration test should be conducted at the desired test level after each adjustment, and prior to the start and end of each day's testing and after any equipment adjustment or failure.

Because the arc does not follow a path that is equidistant from each sensor, the results vary. At 8 000 A, the highest total heat measured with any sensor shall be between 377 kW·s/m^2 and 461 kW·s/m^2 and the average total heat for all sensors shall be at least 251 kW·s/m^2. If these values are not achieved, check the calibration of the sensor system, electrical conditions, and the physical set-up of the apparatus and repeat the calibration exposure until the required results are obtained.

9.5 Confirmation of test apparatus setting

Confirm the test apparatus setting for each test. Values reported shall be peak arc current, r.m.s. arc current, arc duration, arc energy, and arc voltage. A graph of the arc current shall be plotted to ensure proper waveform. In addition, the ambient temperature and relative humidity shall be recorded.

10 Apparatus care and maintenance

10.1 Surface reconditioning

Wipe each sensor face immediately after each test, while hot, to remove any decomposition products which condense and could be a source of future error. If a deposit collects and appears to be thicker than a thin layer of paint, or is irregular, the sensor surface requires reconditioning. Carefully clean the cooled sensor with acetone or petroleum solvent, making certain to follow safe handling practices. Repaint the surface with a thin layer of flat, black, high temperature spray paint. Use the same paint on all sensors and ensure that the paint is dry before running the next test.

10.2 Care of sensor boards and mannequins

Sensor boards and mannequins shall be kept dry. For outdoor tests, they shall be covered during long periods between tests to prevent excess temperature rise resulting from exposure to the sun. Due to the destructive nature of the electric arc, they should be covered with the same paint as the sensors. They should be re-coated periodically to reduce deterioration.

11 Test procedures

11.1 Test parameters

Test parameters shall consist of an arc current of 8 kA ± 1 kA, a 300 mm electrode gap, stainless steel electrodes and a 300 mm distance between the arc centre line and the test specimen surface.

11.2 Order of tests

Each test shall consist of a minimum of three specimens of the same material, one for each of the three two-sensor panels or one for each of the mannequins. To evaluate a single sample of material, a series of a minimum of seven tests shall be run over a range of incident energies, so that the average temperature rise of at least 20 % of the two-sensor panels or the four-sensor mannequins are above and at least 20 % below the Stoll curve. Not more than 10 % of the data points shall be greater than 10 °C above or below the Stoll curve. A minimum of 20 data points, the average of two sensor results for each of 20 panels (method A), or the average of four sensor results for each of 20 mannequins (method B) is required for data analysis.

If breakopen occurs (see 3.7), extra tests shall be run to provide an adequate number of data points. The incident energy range shall be achieved by increasing or decreasing the arc duration (cycles). The purpose of these tests is to achieve an average temperature rise for each panel, which is in the same range as the Stoll curve.

11.3 Initial temperature

Adjust the temperature of the sensors to between 25 °C and 35 °C.

Cool the sensors after exposure with a jet of air or by contact with a cold surface. Confirm that the sensors are at a temperature between 25 °C and 35 °C.

11.4 Specimen mounting

11.4.1 Method A panels

The specimen shall be fixed to the sensor board without stretching the material and in a manner that permits the specimen to shrink during arc exposure. This has been achieved with a material clamping system (see figure 11). The clamping system, consisting of four clamps, holds the specimen to the sensor board and allows the specimen to shrink during arc exposure. Each clamp within the clamping system applies between 4,4 N and 6,7 N to secure the material to the panel. Other means of mounting, which meet the above objectives, may also be employed. If multiple-layer specimens are used, they shall be mounted in a manner that represents normal layering of wearing apparel.

11.4.2 Method B mannequins

The specimens shall be mounted in a manner that represents normal layering of wearing apparel. The mannequin shall be dressed in a test specimen with all the buttons fastened. A 1 500 g mass in the shape of a semicircle shall be attached to the folded bottom edge of the specimen with five clips on the semicircle mass. The test specimen shall be smoothed over the front of the mannequin and excess material gathered behind the mannequin. The arms shall hang at the side of the mannequin and shall not protrude closer to the arc than the chest area.

11.5 Specimen data

Record specimen data including

- identification number;
- order of layering with outer layer listed first;
- material type;
- actual basis weight;
- weave/knit type;
- colour;
- number of specimens tested.

11.6 Test protocol

Mount the fuse wire on electrodes.

Exercise all safety precautions and ensure all persons are in a safe area.

Expose test specimens to the electric arc.

Shut off the electric supply, ventilate the test area at the completion of the data acquisition period and apply the protective grounds (see clause 7).

Extinguish any flames or fire, unless it was predetermined to let the specimen(s) burn until consumed.

Record the thermal and electrical data and material response as required in clause 13.

Inspect and recondition the sensors, if required, and adjust the electrodes to their correct position and gap.

12 Interpretation of results

12.1 Heat transfer

12.1.1 Determining time zero

Due to the electrical noise typically associated with conducting tests of this type, it is difficult to get a reliable trigger signal at the initiation of the arc. The starting time of the arc can be reliably determined, however, for each test by using the following analysis.

For each sensor's curve, plot the difference between the curve and a line drawn from the start of the data stream to some point on the rising temperature region of the curve. Find the maximum of this difference plot. The point at which this maximum occurs is the best estimate of the arc initiation time for that sensor. These arc initiation points are usually very consistent within a test, but the median of these points for all sensors should be used as the initiation point for all of the sensors.

NOTE Other satisfactory methods are available to determine time zero and may be utilized.

12.1.2 Plotting sensor response

Once the initiation point is determined, the data collected up to the initiation point can be averaged to obtain a baseline for each sensor curve. The baseline of each individual curve is then subtracted from each of the data points to yield a zero-based temperature-rise curve. With the initiation point determined, and the sampling time known, the temperature-rise curve can be plotted with the correct time scale (see figure 10). These procedures can easily be automated in a spreadsheet.

12.1.3 Sensor response versus Stoll curve

The Stoll curve is defined by the values in table 1. Overlay the Stoll curve on the plot of the sensor responses. Create a data file which interpolates between the Stoll curve data points in table 1 so that Stoll curve data is available at each time interval at which temperature rise data is recorded.

Table 1 – Human tissue tolerance to heat, second-degree burn [1]

Exposure time	Heat flux	Total heat	Calorimeter equivalent iron/constantan thermocouple	
s	kW/m^2	kW·s/m^2	ΔT °C	ΔmV
1	50	50	8,9	0,46
2	31	61	10,8	0,57
3	23	69	12,2	0,63
4	19	75	13,3	0,69
5	16	80	14,1	0,72
6	14	85	15,1	0,78
7	13	88	15,5	0,80
8	11,5	92	16,2	0,83
9	10,6	95	16,8	0,86
10	9,8	98	17,3	0,89
11	9,2	101	17,8	0,92
12	8,6	103	18,2	0,94
13	8,1	106	18,7	0,97
14	7,7	108	19,1	0,99
15	7,4	111	19,7	1,02
16	7,0	113	19,8	1,03
17	6,7	114	20,2	1,04
18	6,4	116	20,6	1,06
19	6,2	118	20,8	1,08
20	6,0	120	21,2	1,10
25	5,1	128	22,6	1,17
30	4,5	134	23,8	1,23

From the temperature rise data for the two sensors on each panel or the four sensors on each mannequin, create an average temperature-rise curve (rT_{avg}). Compare this curve, rT_{avg} for each panel or mannequin with the Stoll curve.

For the rT_{avg} curves which are above the Stoll curve, record the maximum difference in degrees Celsius between the rT_{avg} curve and the Stoll curve. These values will be positive in sign indicating the rT_{avg} curves are above the Stoll curve. Label this positive value $r_{\text{Stoll,avg}}$ for the maximum difference between the Stoll curve and the rT_{avg} curve.

For the rT_{avg} curves which are below the Stoll curve, record the minimum difference in degrees Celsius between the rT_{avg} curve and the Stoll curve. These values will be negative in sign indicating the rT_{avg} curves are below the Stoll curve. Label this negative value $r_{\mathrm{Stoll,avg}}$ for the minimum difference between the Stoll curve and the rT_{avg} curve.

12.1.4 Incident energy (E_{i}) monitor sensor responses

For each panel or mannequin in an arc exposure, calculate the average of the maximum rise, $rT_{\mathrm{avg,max}}$, for the two adjacent monitor sensors. Convert this $rT_{\mathrm{avg,max}}$ into kW·s/m^2 by multiplying by the copper calorimeter conversion constant of 5,65 kW·s/m^2 K to determine the incident exposure energy, E_{i}, for each panel or mannequin in an arc exposure.

12.1.5 Determining arc thermal performance values

For each panel or mannequin, plot the positive value or the negative value of $r_{\mathrm{Stoll,avg}}$ as the horizontal axis and E_{i} as the vertical axis. For each arc exposure, the three panels will create three data points, the mannequins will create from one to three data points (depending on the number of mannequins used), of $r_{\mathrm{Stoll,avg}}$ versus E_{i}. In order to have sufficient data for analysis, at least 20 data points, representing 20 panels or 20 mannequins, shall be obtained with not less than 20 % of the data being positive and not less than 20 % of the data being negative values. No more than 10 % of the data points shall deviate from the Stoll curve by more than 5 °C. All data points meeting these criteria shall be used in the calculation of ATPV and HAF. If ATPV cannot be calculated due to breakopen, use the method of data analysis in 12.2.

12.1.6 Calculating the confidence intervals

Create the best fit straight line for the $r_{\mathrm{Stoll,avg}}$ data points and determine the 95 % confidence intervals for average and for point values. To calculate the confidence intervals, estimate the variance (sigma squared) by:

$$s^2 = \frac{S_{\mathrm{R}}}{n-2}$$

where $S_{\mathrm{R}} = \Sigma(y-\bar{y})^2 - b^2\Sigma(x-\bar{x})^2 = \Sigma(y-\bar{y})^2 - b\Sigma(x-\bar{x})(y-\bar{y})$

Then the variance of the estimate of y at some particular x_0 can be calculated from the expressions:

$$\hat{V}(\hat{y}_0)_{\mathrm{point}} = \left[1+\frac{1}{n}+\frac{(x_0-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right]s^2$$

$$\hat{V}(\hat{y}_0)_{\mathrm{avg}} = \left[\frac{1}{n}+\frac{(x_0-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right]s^2$$

A $1 - \alpha$ confidence interval for the estimate of y at some particular x_0 is then given by:

$$\hat{y}_0 \pm t_{\alpha/2}\sqrt{\hat{V}(\hat{y}_0)_{\text{avg}}}$$

$$\hat{y}_0 \pm t_{\alpha/2}\sqrt{\hat{V}(\hat{y}_0)_{\text{point}}}$$

where t has $n - 2$ degrees of freedom. Software packages may be used to determine the 95 % confidence interval band for the best fit line from 12.1.6.

12.1.7 Determination of the arc thermal performance value (ATPV)

ATPV is the E_i value where $r_{\text{Stoll,avg}}$ equals zero based on the best fit line from 12.1.6. The ATPV 95 % confidence interval is the E_i interval formed by the 95 % confidence band at $r_{\text{Stoll,avg}}$ equals zero.

12.1.8 Graphic depiction of ATPV

The readily available statistical analysis programs for determining the ATPV 95 % confidence interval require that E_i be plotted on the vertical axis and $r_{\text{Stoll,avg}}$ on the horizontal axis. However, this plotting arrangement tends to be counter-intuitive. Consequently, once the 95 % confidence interval is determined according to 12.1.7, the plot of $r_{\text{Stoll,avg}}$ on E_i shall be reconstructed with $r_{\text{Stoll,avg}}$ plotted on the vertical axis and E_i plotted on the horizontal axis.

12.1.9 Determination of heat attenuation factor (HAF)

Determine the maximum rT_{max} for the two sensors on each panel. Calculate the average of the rT_{max} for the two sensors of each panel and label this as $rT_{\text{avg,max}}$. For each panel of each exposure divide $rT_{\text{avg,max}}$ by the $rT_{\text{max,min}}$ for the two monitor sensors (from 12.1.4) adjacent to the panel and identify this value as E_t (fraction of the incident energy which is transmitted through the specimen). A HAF data point (haf) for each panel is calculated according to the formula:

$$haf = 100(1 - E_t)$$

The HAF value is then determined by plotting all the haf values for each panel on the vertical axis versus the E_i for each panel on the horizontal axis. At least 20 data points representing 20 panels shall be used. The best fit line is plotted through these data points and the 95 % confidence interval is determined for the best fit line. HAF is the value indicated by the best fit line at the E_i value equal to the ATPV. The HAF 95 % confidence interval is determined by the 95 % confidence interval values at the E_i equal to the ATPV.

Refer to annex B for a review and explanation of the methods and formulas for determining the ATPV and HAF.

12.2 Determination of breakopen threshold energy

If the required 20 % of the data over the Stoll curve cannot be generated without breakopen, an arc thermal protective value cannot be generated.

In multiple-layer specimens of flame-resistant material, all the layers shall break open to meet the definition in 3.7. In multiple-layer specimens, if some of the layers are ignitable, breakopen occurs when these layers are exposed.

At the highest E_i value below the Stoll curve for which the specimens did not exhibit breakopen, repeat the tests to obtain six more data points. If no breakopen occurs, this E_i value is the breakopen threshold energy (E_{BT}).

If breakopen occurs, repeat the above to obtain 10 data points at the highest E_i value below this breakopen E_i. If no breakopen occurs, this E_i value is the breakopen threshold energy (E_{BT}) but if breakopen occurs, a value for breakopen threshold energy cannot be generated.

12.3 Visual inspection

Observe the effect of the exposure on the fabric specimens and, after the exposed specimens have cooled, carefully remove the fabric and other layers from the panel noting any additional effects from the exposure. This may be described by one or more of the following terms which are defined in clause 3:

- breakopen;
- melting;
- dripping;
- charring;
- embrittlement;
- shrinkage;
- ignition.

13 Test report

State that the test has been performed in accordance with this test method, and report the method used (method A or method B) in addition to the following information:

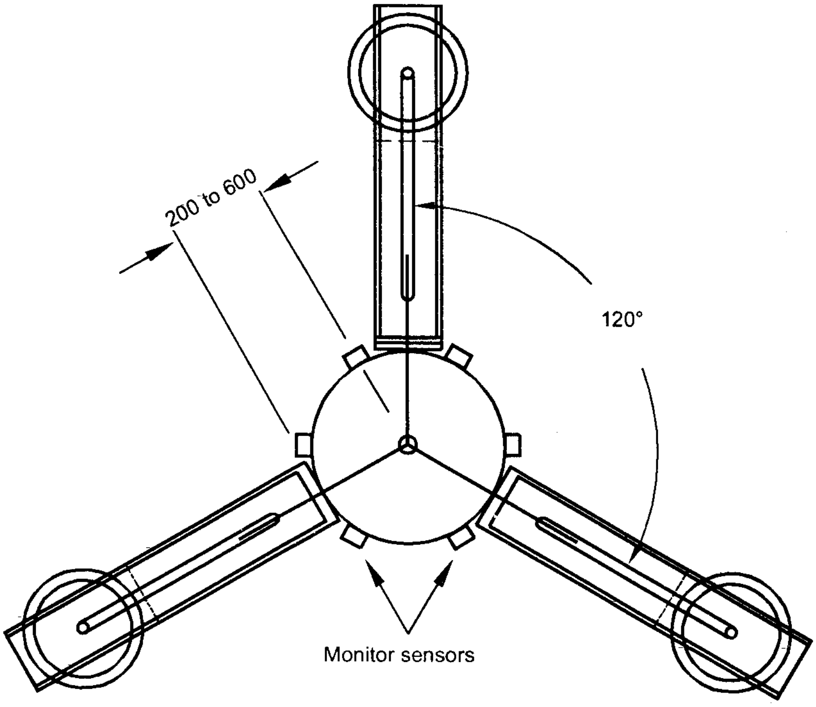
- specimen mounting as indicated in 11.4;
- specimen data as indicated in 11.5;
- conditions of each test, including
  - test number,
  - r.m.s. arc current,
  - peak arc current,
  - arc gap,
  - arc duration,
  - arc energy,
  - plot of arc current;

- test data including
  - test number,
  - specimen(s),
  - order of layers,
  - distance from the arc centre line to the panel or mannequin surface,
  - visual inspection as outlined in 12.3,
  - plot of the response of the two monitor sensors and the two panel sensors for each panel test, or the four mannequin sensors for each mannequin test,
  - plot of the average response from the two panel sensors and from the two monitor sensors for each panel test (method A), or the average response of the four mannequin sensors and the two monitor sensors for each mannequin test (method B),
  - ATPV and ATPV 95 % confidence intervals,
  - plot of $r_{\mathrm{Stoll,avg}}$ on E_{i},
  - HAF and HAF 95 % confidence intervals,
  - plot of HAF on E_{i},
  - plot of the incident energy distribution E_{i} (bare) from the bare shot analysis (without test specimen).

Report any abnormalities relating to the test apparatus.

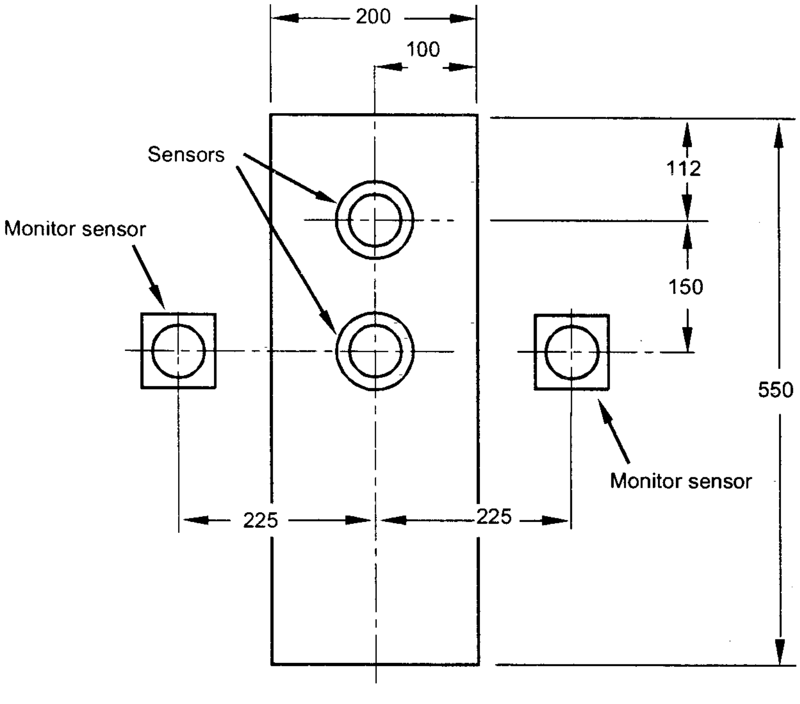
If alternate electrodes are used, report size and type.

Return the exposed specimens, plots, test data, and unused specimens to the person requesting the test, in accordance with any prior arrangement. All test specimens shall be marked with a reference to the test number, date, etc.



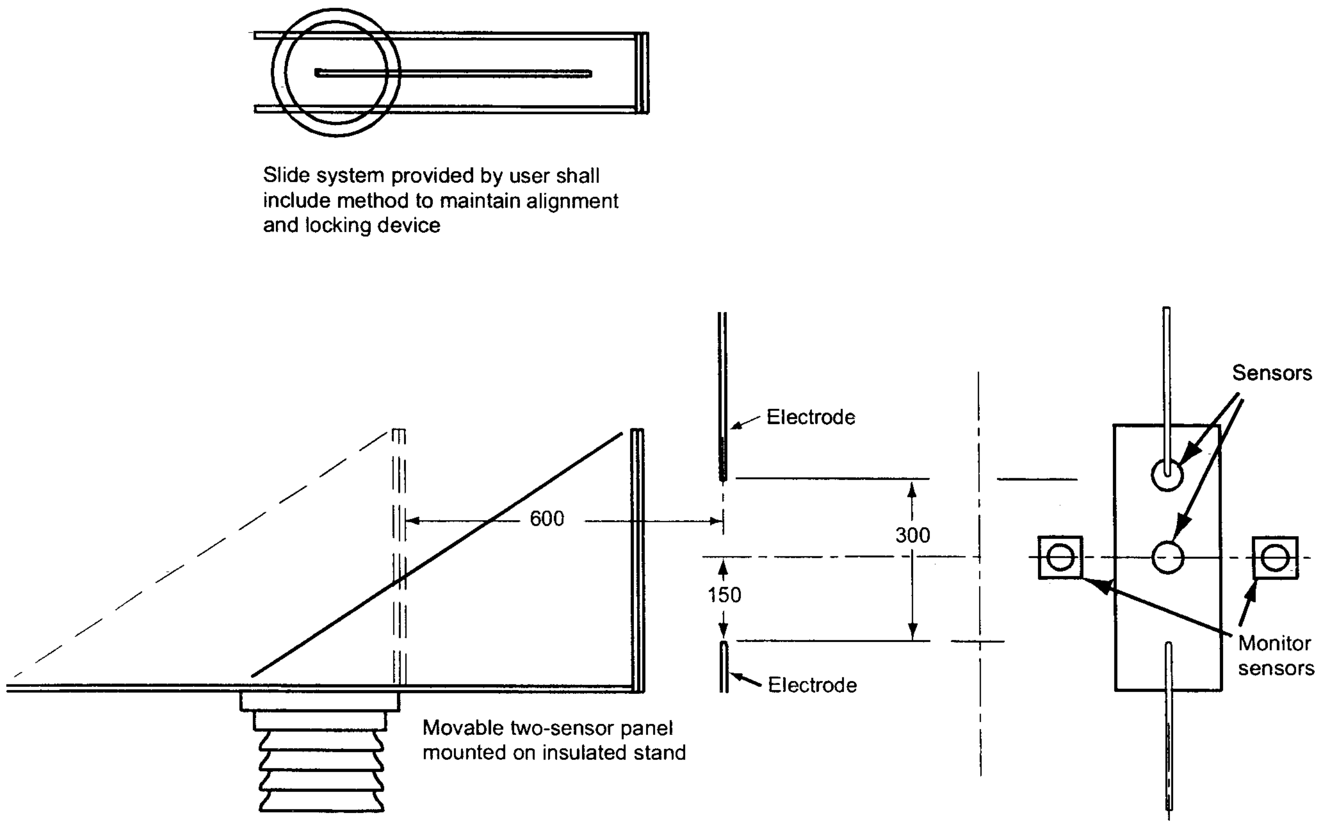
Dimensions in millimetres

Figure 1 – Method A – Arrangement of three-panel sensors with monitor sensors (plan view)



Dimensions in millimetres

Figure 2 – Method A – Two-sensor panel (face view) with monitor sensors



Slide system provided by user shall include method to maintain alignment and locking device

Dimensions in millimetres

Figure 3 – Method A – Sliding two-sensor panel

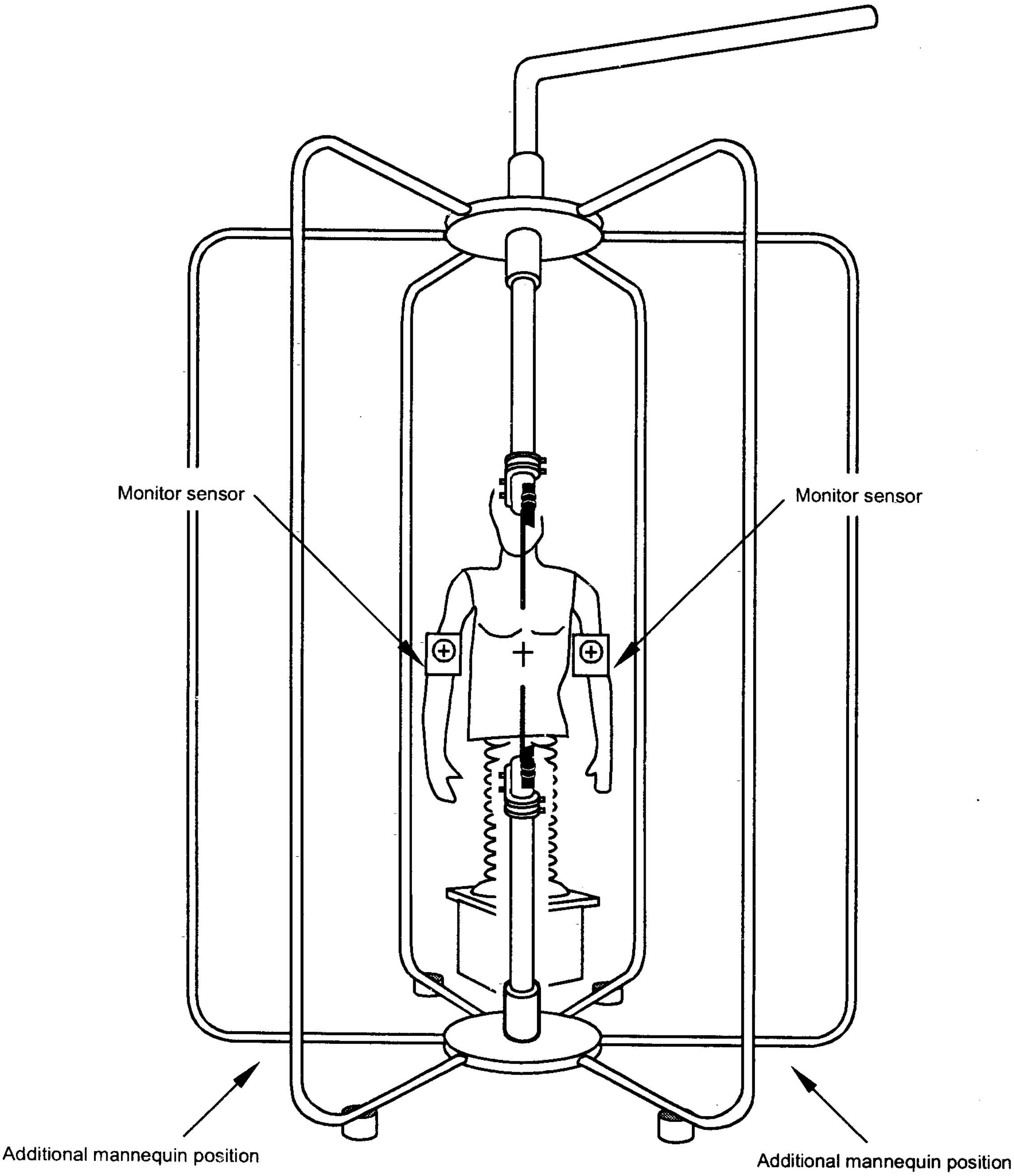
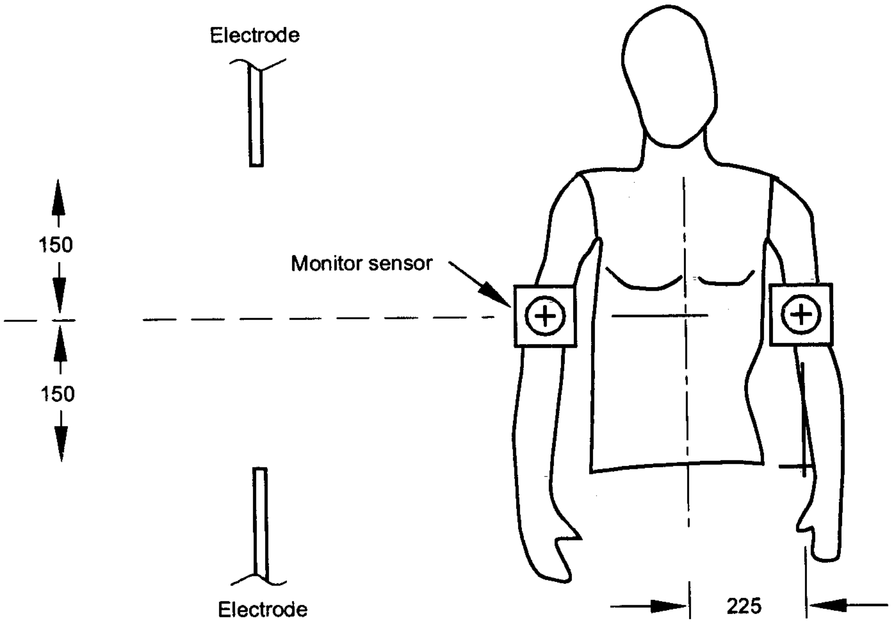
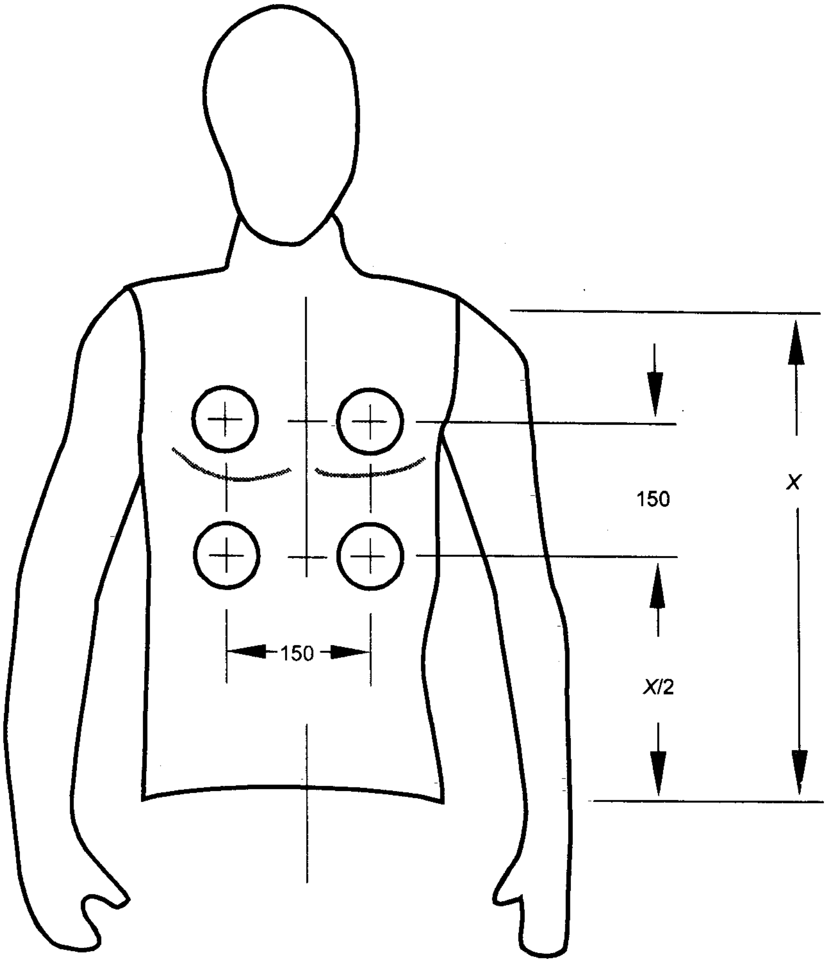


Figure 4 – Supply bus and arc electrodes showing mannequin(s) position(s)



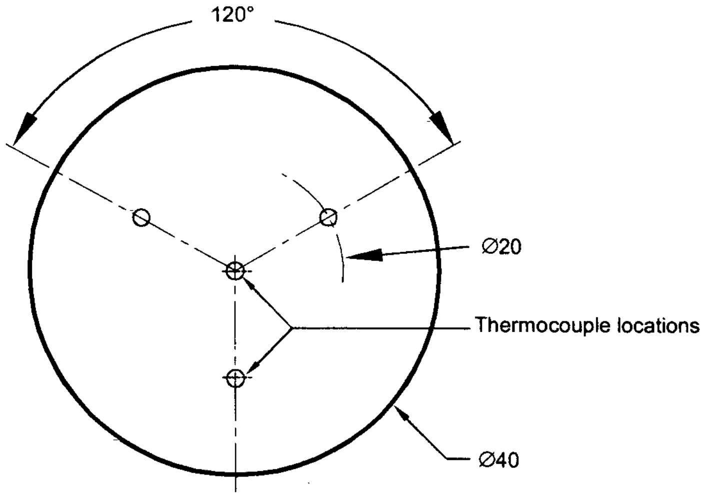
Dimensions in millimetres

Figure 5 – Mannequin with monitor sensors



Dimensions in millimetres

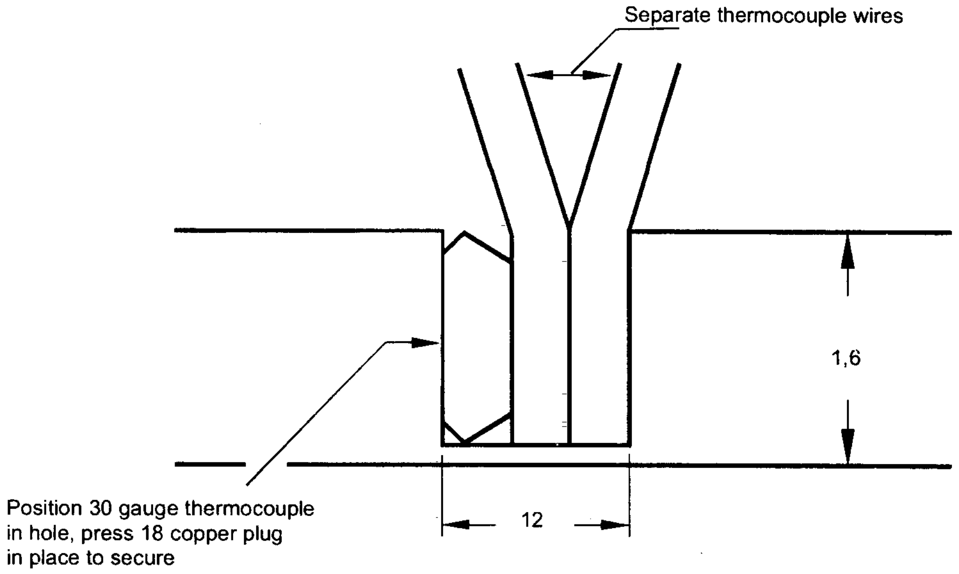
Figure 6 – Four-sensor face view



Sensor of electrical grade copper

Dimensions in millimetres

Figure 7a – Installation of thermocouples in the calorimeter


Separate thermocouple wires
1,6
12
Position 30 gauge thermocouple in hole, press 18 copper plug in place to secure

Dimensions in millimetres

Heat flux (q)

q = (mass × copper heat capacity × temperature rise)/(area of disc × time)

$$q = \frac{mC_{\mathrm{p}}\Delta T}{A\Delta\theta}$$

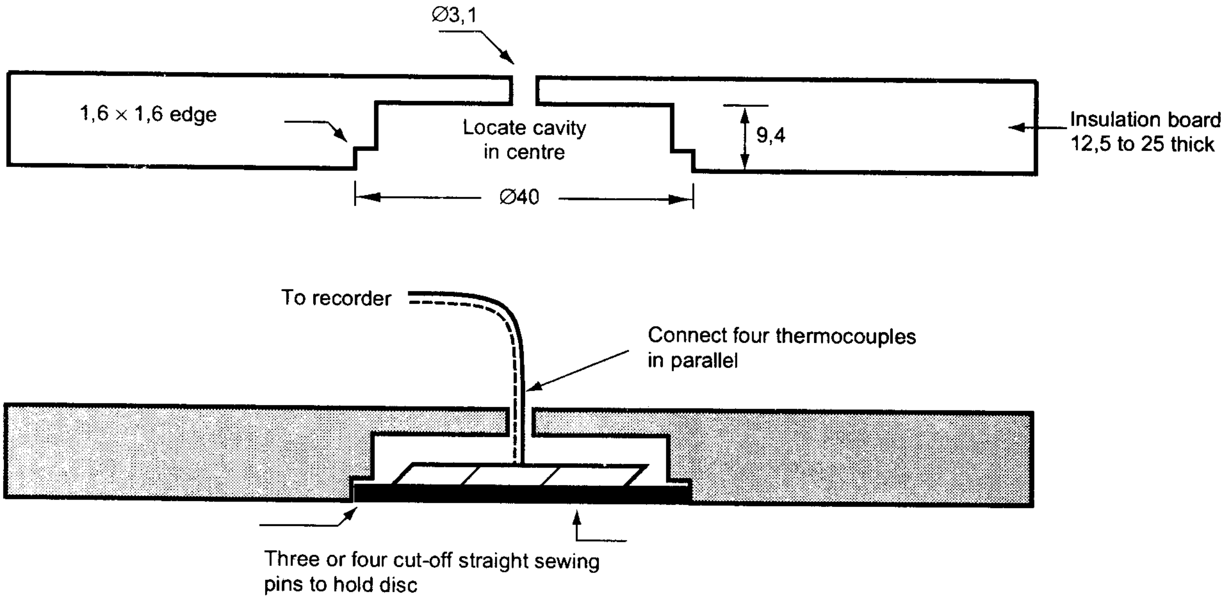
C_{p} = 0,394 4 Ws/g °C

For a disc area of 12,56 cm^2 and a disc weight of 18 g,

q = $(5{,}65\ \Delta T)/\Delta\theta$ in kW/m^2

Figure 7b – Thermocouple wire installation – Hole detail and method of securing thermocouple

Figure 7 – Calorimeter and thermocouple details


Ø3,1
1,6 × 1,6 edge
Locate cavity in centre
9,4
Insulation board 12,5 to 25 thick
Ø40
To recorder
Connect four thermocouples in parallel
Three or four cut-off straight sewing pins to hold disc

Dimensions in millimetres

Figure 8 – Typical installation of the calorimeter in the sensor and monitor sensor

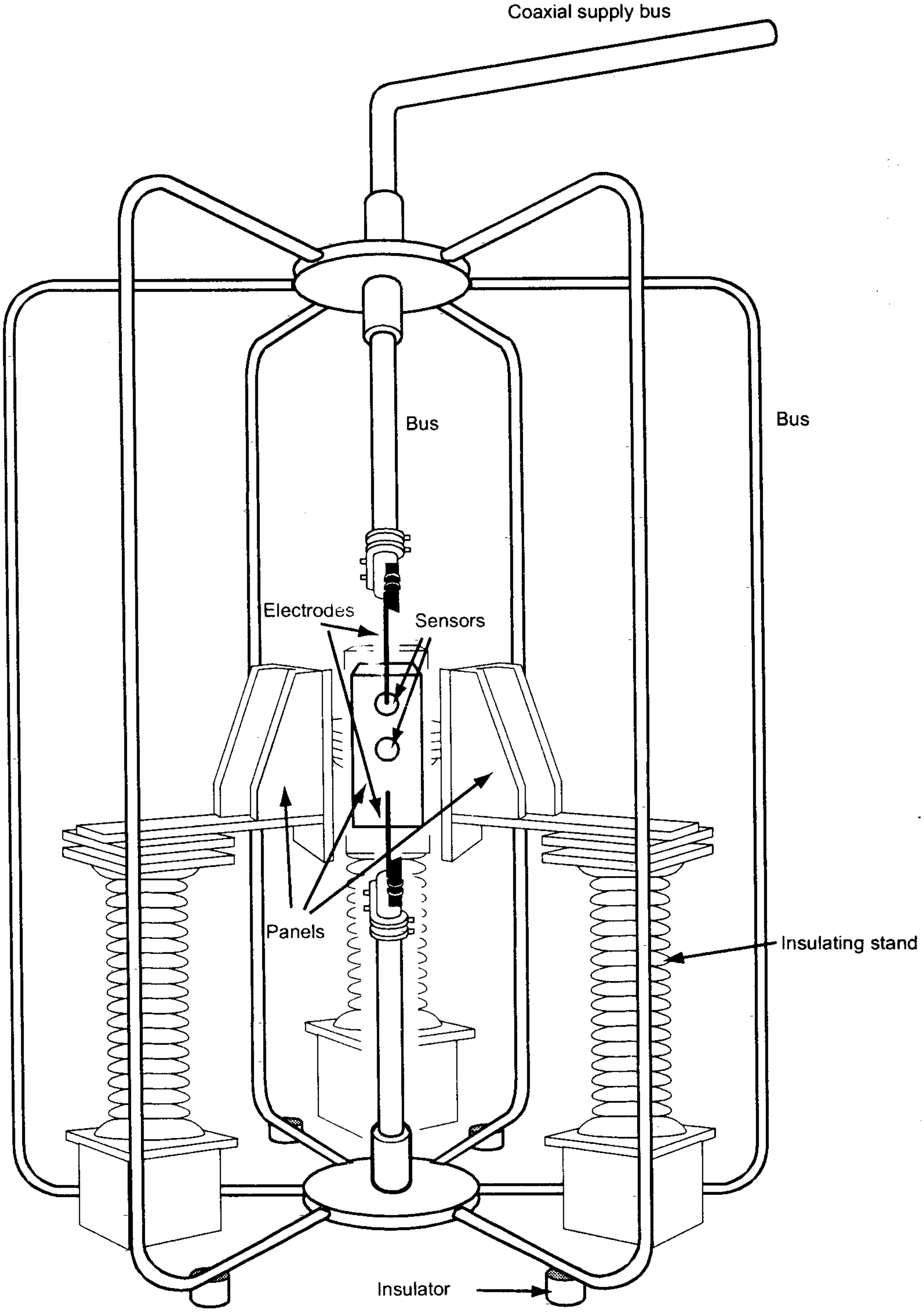


Figure 9 – Supply bus and arc electrodes for panels

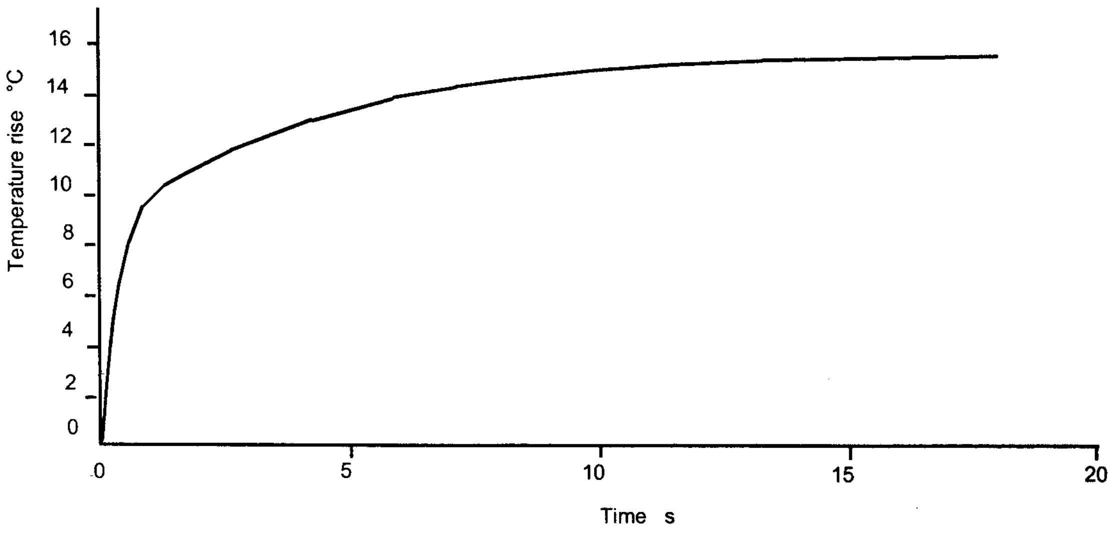
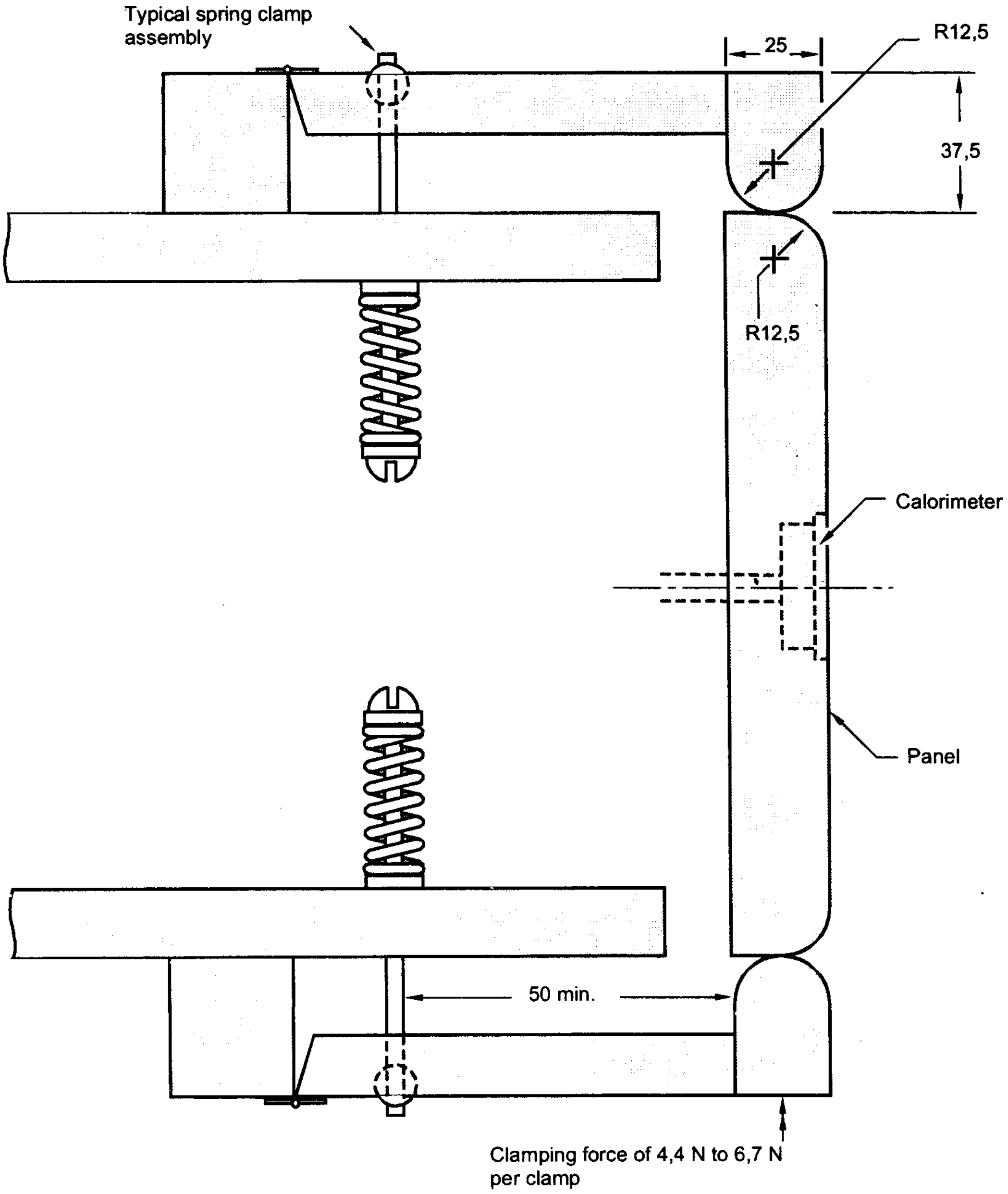


Figure 10 – Typical sensor temperature-rise curve with time scale and baseline correction


Typical spring clamp assembly
25
R12,5
37,5
R12,5
Calorimeter
Panel
50 min.
Clamping force of 4,4 N to 6,7 N per clamp

Dimensions in millimetres

NOTE Place one clamp on each panel edge. Four clamps are required per panel.

Figure 11 – Typical material clamping assembly

Annex A
(normative)

Measurement of char length

This test is based on annex C of ISO 15025.

Outer material shall be tested with procedure B of ISO 15025 (bottom-edge ignition). Each layer of material assemblies shall also be tested with procedure B.

The char length shall be measured as follows.

The char length shall be determined by measuring the length of the tear through the centre of the charred area.

- The specimen shall be folded lengthwise and creased, by hand, along a line through the highest peak of the charred area.
- A hook, made of steel wire, using a 76 mm length of wire and bent 13 mm from one end to form a 45° hook, shall be inserted into the specimen (or a hole of 6 mm diameter or less pinched out for the hook) at one side of the charred area 6 mm from the adjacent outside edge and 60 mm from the lower end.
- A weight of sufficient mass is required such that the mass of the weight and hook together shall equal the total tearing load required by table A.1. The total tearing load for determining char length shall be based on the mass of the test specimen and shall be determined from table A.1.

Table A.1 – Total tearing load

Mass of test specimen material g/m^2	**Total tearing load for determining the char length** kg
50 to 200	0,1
Over 200 to 500	0,2
Over 500 to 800	0,3
Over 800	0,45

- A tearing force shall be applied gently to the test specimen by grasping the corner of the specimen at the opposite edge of the char from the load, and raising the specimen and weight clear of the supporting surface. The end of the tear shall be marked on the edge and the char length measurement made along the undamaged edge.

Annex B
(informative)

Statistical analysis – Review of the methods and formulas for determining ATPV and HAF

This review examines the statistical methods used to obtain the ATPV, the HAF, and related performance factors from a set of experimental data for a given type of clothing material. This review does not examine the validity of the method used to obtain the experimental points.

B.1 Background

The arc test of a piece of textile material on a sensor panel yields three values:

a) E_i the incident energy in kW·s/m^2;

b) dS the sensor response as a difference in temperature (°C), either negative or positive, from the Stoll curve;

c) E_t the transmitted energy, as a fraction of the incident energy.

In the case of breakopen, a different analysis applies, as described in 12.2.

B.2 Determining ATPV

A complete set of data for one type of clothing will consist of at least 20 tests, with not less than 20 % of the tests having dS positive and not less than 20 % of the tests having dS negative. A graph of the tests showing dS as a function of E_i will thus show a set of points grouped around the line $dS = 0$.

The ATPV can be obtained from the graph of the data set in two steps:

a) evaluate and plot the best-fit line;

b) determine the E_i value at the intercept of the best-fit line with the line $dS = 0$.

The process of evaluating the best-fit line is not necessarily simple. The algorithms in commercial software for linear least-squares regression assume that all the errors in a set of points (x_i, y_i), for i = 1 to n, are in the y_i co-ordinate. Here that would be the dS values. From the nature of the arc tests, however, we know that there are errors in the E_i values too. Thus, any regression of dS on E_i, or of E_i on dS, only accounts for the errors in one co-ordinate set. Furthermore, the two regressions yield different results. In the search for ATPV, however, the two regressions give similar results by virtue of the fact that the ATPV is near the mean of the E_i values. This is guaranteed by the requirement that the test points be grouped around the value $dS = 0$.

One way to handle the problem is to do both regressions and split the difference. A better way is to evaluate the least-squares best fit by assuming that there are errors in both co-ordinates. Commercial software can handle this approach by modifying the way the linear regression is solved. The method requires some iterations as the problem is inherently non-linear, although the resulting fit is definitely a straight line.

B.3 Determining ATPV 95 %

Intuitively, the value of ATPV 95 % is the value of the incident energy where the probability of dS exceeding zero is 5 %, based on the best-fit line to the data set. This corresponds to predicting a value for dS at that incident energy.

The prediction of a single point from a best fit to a data set is different from stating the confidence limits of the best-fit line itself, as noted in 12.1.6 but not fully interpreted. Commercial software, again, usually provides the "confidence limits" of the linear fit. These confidence limits apply to the line as a whole, and not to predictions of single points. Note also that the confidence limits are two-sided, i.e. the 95 % confidence limits confine the best-fit line from above and below. If we want a 95 % probability of not exceeding $dS = 0$, then we should look for the confidence limit such that the area above the upper limit is 5 % probability. For a two-sided distribution, this means that the area below the lower limit is also 5 % and so the area between the limits is 90 %. Thus, for a 95 % probability of not exceeding $dS = 0$, use the upper limit at the level of 90 % confidence.

Subclause 12.1.6 includes the formula for predicting a value of a single point and its prediction limits:

$$y_{95} = \hat{y}_0 \pm t_{95}\sqrt{\hat{V}(\hat{y}_0)_{\text{point}}} \tag{B.1}$$

where

$$\hat{V}(\hat{y}_0)_{\text{point}} = \left[1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{\sum (x - \bar{x})^2}\right] s^2 \tag{B.2}$$

and

$$s^2 = \frac{1}{n-2}\left[\sum (y - \bar{y})^2 - b^2 \sum (x - \bar{x})^2\right] \tag{B.3}$$

In the above equations:

n is the number of sample points;

$\hat{y}_0$ is the predicted value (i.e. dS);

x_0 is the incident energy E_i (i.e. ATPV 95 %) at the predicted value;

$\bar{x}$ is the mean value of the incident energies;

$\bar{y}$ is the mean value of the sensor responses (dS);

b is the slope of the best-fit line;

t_{95} is the value of the t-distribution for (n-2) degrees of freedom at a two-sided probability of 0,95.

For example, if there are 20 sample points then n is 20, there are 18 degrees of freedom, and t_{95} is 2,101. As noted above, to obtain the 95 % probability of not exceeding $dS = 0$, one should really use t_{90} here, which is 1,734. It is also worth noting that t_{90} for a two-sided distribution is equivalent to t_{95} for a one-sided distribution.

The problem of calculating ATPV 95 % reduces to solving the above equations for x_0, given that the point (x_0, $\hat{y}_0$) lies on the best-fit line, so that the upper value of y_{95} is identically zero. Note that the equation of the best-fit line at x_0 can be written as

$$\hat{y}_0 - \bar{y} = b(x_0 - \bar{x}) \tag{B.4}$$

The solution for x_0 is the root of a quadratic equation, straightforward to do, but it may be easier to find graphically by calculating y_{95} for a range of X.

$$x_0 = \bar{x} + \frac{-b\bar{y} \pm \sqrt{b^2\bar{y}^2 - \left(b^2 - \dfrac{t_{95}^2 s^2}{\sum (x - \bar{x})^2}\right)\left(\bar{y}^2 - t_{95}^2 s^2\left(1 + \dfrac{1}{n}\right)\right)}}{\left(b^2 - \dfrac{t_{95}^2 s^2}{\sum (x - \bar{x})^2}\right)} \tag{B.5}$$

The choice of plus or minus sign in the above expression can be determined by substituting the value into the set of equations to verify y_{95} is identically zero.

B.4 Heat attenuation factor

The heat attenuation factor (HAF) is a measure of the amount of heat not transmitted through a piece of material. If the material does not change its physical state for any incident energy in the data set, then the heat attenuation factor should be a constant. If the HAF is a constant then a graph of HAF as a function of incident energy will be a straight line of zero slope. The following discussion assumes that the HAF values are a sample of a normal distribution.

The true value of HAF is unknown. The best estimate of HAF is the mean of all the values, independent of the value of ATPV. The distribution of HAF values about the mean can be characterized by calculating the standard deviation from the data set. Then the HAF 95 % confidence interval can be determined using the t-distribution. In the following equations $\bar{x}$ is the mean of the n sample values of E_t, s is the sample standard deviation, T is the sample statistic for the true mean μ, and a is the value from the t-distribution for n-1 degrees of freedom.

$$s^2 = \frac{\sum (x - \bar{x})^2}{n - 1} \tag{B.6}$$

$$T = \sqrt{n}(\bar{x} - \mu) / s \tag{B.7}$$

$$P(-a < T < a) = 0{,}95 \tag{B.8}$$

$$\bar{x} - \frac{sa}{\sqrt{n}} < \mu < \bar{x} + \frac{sa}{\sqrt{n}} \tag{B.9}$$

Equation (B.9) is a statement of the confidence limits for the true value of HAF in terms of the sample mean and sample standard deviation. For example, for 20 samples there are 19 degrees of freedom and a is 2,093. (Note that as the number of degrees of freedom increases, the limiting value of a is 1,96, the same as when the population standard deviation is known. Note also that the probability used for HAF 95 % is two-sided, whereas the probability for ATPV 95 % is really only one-sided.) [2]

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